ERDC TN-DOER-E32
August 2012

A Fish Larvae and Egg Exposure System (FLEES) for Evaluating the Effects of Suspended Sediments on Aquatic Life

by Charles H. Lutz, Douglas G. Clarke, and Burton C. Suedel

PURPOSE: The purpose of this technical note is to describe a laboratory system. The laboratory system was developed to expose early life history stages of fish and shellfish to specified concentrations and durations of suspended sediment in a controlled laboratory environment. This allows for the design of experiments that simulate resuspension of sediment as a result of dredging operations or other factors such as vessel traffic, freshets, or storms. The design and construction of the Fish Larvae and Egg Exposure System (FLEES) permits studies to be performed using various aquatic species and life stages (e.g., walleye eggs, salmonid larvae, oysters) that are driving environmental windows on dredging project operations at one or more sites. By using the FLEES, exposure-response curves can be developed between aquatic organism health and suspended sediment concentrations, thus generating effects data that are needed to evaluate the effectiveness and necessity of EWs intended to protect the selected species.

BACKGROUND AND PROBLEM: Environmental windows (EWs) associated with dredging operations can be controversial. Over time, EWs (periods during which dredging is allowed to proceed) have become increasingly constrained by a multitude of species-specific restrictions, thus greatly limiting the amount of time available to dredge waterways. The production of suspended sediment plumes during fish migration or spawning and the suspended sediment deposition on fish spawning grounds at dredging or placement sites has been cited as a mechanism by which dredging operations could adversely affect natural resources (Reine et al. 1998; Clarke and Wilber 2000; Wilber and Clarke 2001). However, EWs have been commonly established by negotiation and conservative subjective opinion in large part due to the absence of suspended sediment and sediment deposition effects data (NRC 2001; Suedel et al. 2008). Corps personnel charged with addressing resource agency concerns about these potential impacts are challenged because there are so few data for species that are driving EWs, so evaluating the likelihood of adverse impacts is difficult and fraught with uncertainty. The FLEES can generate species-specific data to develop exposure-response curves for select life stages of species of concern when exposed to suspended sediments.

FISH LARVAE AND EGG EXPOSURE SYSTEM (FLEES): The FLEES is a flow-through exposure facility that generates controllable suspended sediment concentrations in multiple experimental aquaria. FLEES consists of three modules, each containing five aquaria inside a 500 L water bath used for temperature control (Figures 1 and 2). Each water bath uses a combination heating/cooling unit (Remcor Products Co., Glendale Heights, Illinois, USA) to maintain constant aquaria temperature. The aquaria were constructed from 20 L polyethylene carboys, turned upside down with the bottom removed. A single magnetic drive pump in each aquarium recirculates water, providing energy to maintain sediment in suspension and aerating the water.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 2012**	2. REPORT TYPE	3. DATES COVERED
4. TITLE AND SUBTITLE **A Fish Larvae and Egg Exposure System (FLEES) for Evaluating the Effects of Suspended Sediments on Aquatic Life**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Army Engineer Research and Development Center,Vicksburg,MS,39180**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

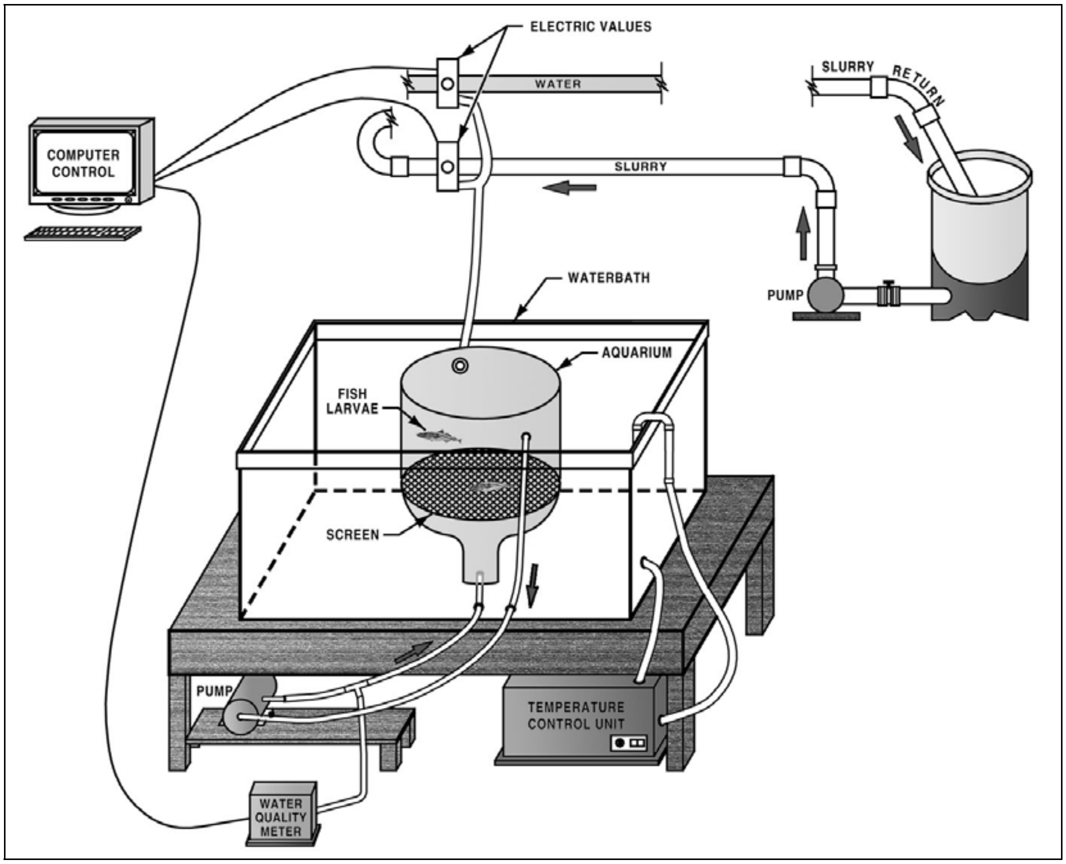

Figure 1. Schematic diagram of the FLEES.

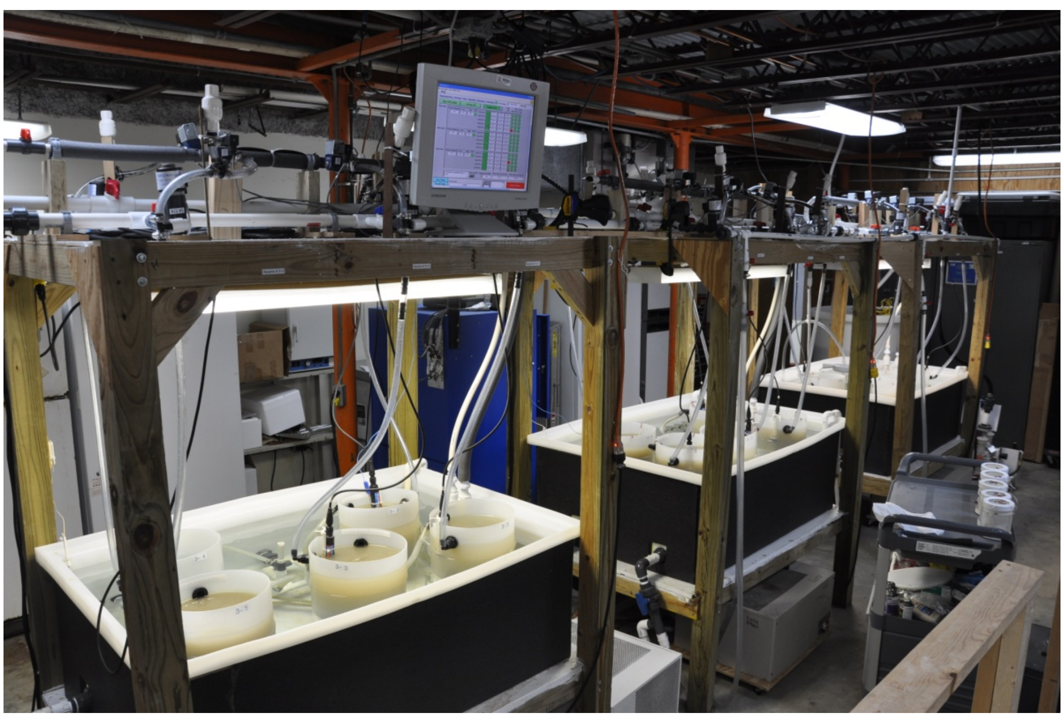

Figure 2. Overview of the FLEES system, showing the three interconnected modules.

Before beginning an experiment, sediment from the area of concern is sieved using a 1 mm sieve to remove debris and coarse particles and is mixed with water to create a slurry with a total suspended solids (TSS) concentration > 1000 mg/L. The slurry is stored in a 375 L cone-bottom polyethylene tank and is continuously mixed by recirculating it using a double diaphragm pump (Wilden Pump and Engineering Co., Grand Terrace, California, USA). This type of pump is not affected by abrasive slurries and provides reliable service. The slurry is pumped from the bottom of the cone-bottom tank, routed through the FLEES and then back into the tank for reuse. The recirculation of the slurry also provides a continuous, renewable source of sediment for maintaining suspended sediment concentrations, which are monitored in each aquarium using optical backscatter sensors (OBS®, Campbell Scientific Inc., Logan, Utah, USA).

Water used in all experiments with freshwater organisms is carbon-filtered tap water from the city of Vicksburg, Mississippi, USA. Aquaria are filled with water at least 48 h before organisms are introduced to allow for aeration and out-gassing of the water. Flow-through water is introduced directly into the aquaria without any “standing” time and the volume is controllable via a setting in the computer program. Dissolved oxygen concentrations are periodically measured based on experimental design. Based on past experience, concentrations remain at or near saturation due to the recirculation and flow-through of water and slurry and the low biomass/water ratio used in these experiments.

FLEES is controlled by a computer running a customized software program (LabView®, National Instruments, Austin, Texas, USA) that interfaces through a data acquisition and control system (National Instruments, Austin, Texas, USA). The software permits each aquarium to be individually controlled for suspended sediment concentration and water inflow rate and allows random assignment of replicates within the FLEES. Once parameters are input into the software, the program monitors suspended sediment concentration in Nephelometric Turbidity Units (NTU) in each aquarium. If NTUs decrease below a preset value, a valve in the slurry recirculation pipe is automatically opened, allowing a small amount of slurry to enter the aquarium. At preset timed intervals, valves are also triggered in the water inflow pipes to flush fresh water into each aquarium, washing any slurry out of the inflow tubing while helping to maintain the desired sediment concentration. The time intervals for monitoring TSS levels (and injection of slurry if needed), water inflow and data collection are dictated by experimental requirements and entered into the computer program. Monitoring data may be collected as often as every minute. The program also has the capability to vary TSS levels over time, allowing an experiment to mimic tidal or other ambient effects on TSS levels. It may also be programmed to repeat specific cycles over a multi-day period. Note that since the monitoring is conducted using optical sensors, a calibration must be performed to determine the relationship between NTU values and TSS concentrations for sediment collected at the project site. This relationship is highly dependent on the properties of the sediment.

Exposure Chambers. There are 15 exposure aquaria: five each in three water baths, allowing for replication. For larger or sessile organisms, exposure often occurs in the open aquarium. Screens are placed over the suction and inflow ports of the pump connections and drains to prevent escape. A screen can also be placed in the bottom of the aquarium to prevent organisms from accessing any sediment that has settled out. For smaller organisms and life stages, various chambers may be constructed to contain them. This prevents organisms from being injured by the

recirculation pump system. Such chambers are suspended in the middle of each aquarium allowing for unimpeded exposure to the suspended sediment (Figures 3 and 4). These smaller exposure chambers may be easily fabricated to meet experimental objectives. Care must be taken to ensure that chamber screens are nitex nylon or other suitable material that will not harm the experimental organisms while ensuring that the screen size is small enough to contain the organism and large enough to permit free flow of suspended sediment through the chamber.

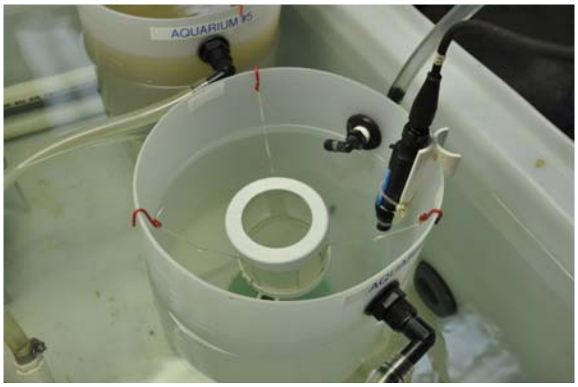

Figure 3. Overview of exposure chamber suspended in an aquarium.

Figure 4. Fish larvae of the appropriate size can be contained within an exposure chamber to reduce the possibility of escape and injury.

Temperature Control. The FLEES can be adjusted to maintain a wide range of temperatures allowing organisms with different temperature requirements to be evaluated. Using insulated water baths, floating plastic beads (2 cm diameter) (Figure 5) and an external heating/cooling system, temperatures were successfully maintained in a range from 13 to 30°C. The temperature of the incoming water and of the ambient air in the laboratory building where the FLEES is located is the biggest contributor to the lower and upper bounds of this range. The goal is to maintain the experimental organisms at their optimal temperature or at the temperature of the field location of interest.

Light Control. Each water bath includes a four foot fluorescent light fixture to provide simulated daylight during the experimental period. These lights are controlled by individual timers that can be programmed to turn the lights on/off at the required intervals.

Suspended Sediment Control. A unique feature of the FLEES is an ability to maintain specific levels of total suspended sediment in each aquarium. Before starting an experimental run, minimum and maximum NTU values are entered into the computer program setting levels for each aquarium. If the measured NTU value drops below the minimum set point, the computer activates an electronic valve attached to the recirculating slurry system allowing a small amount of slurry to be pulsed into that aquarium. The time the valve is allowed to stay open is controlled by the computer program which controls the volume of slurry delivered in each pulse. This setting may be varied as needed. If the maximum NTU limit is exceeded, the computer display screen will indicate that condition with a red light alerting the scientist that the program NTU level for that aquarium may need to be adjusted.

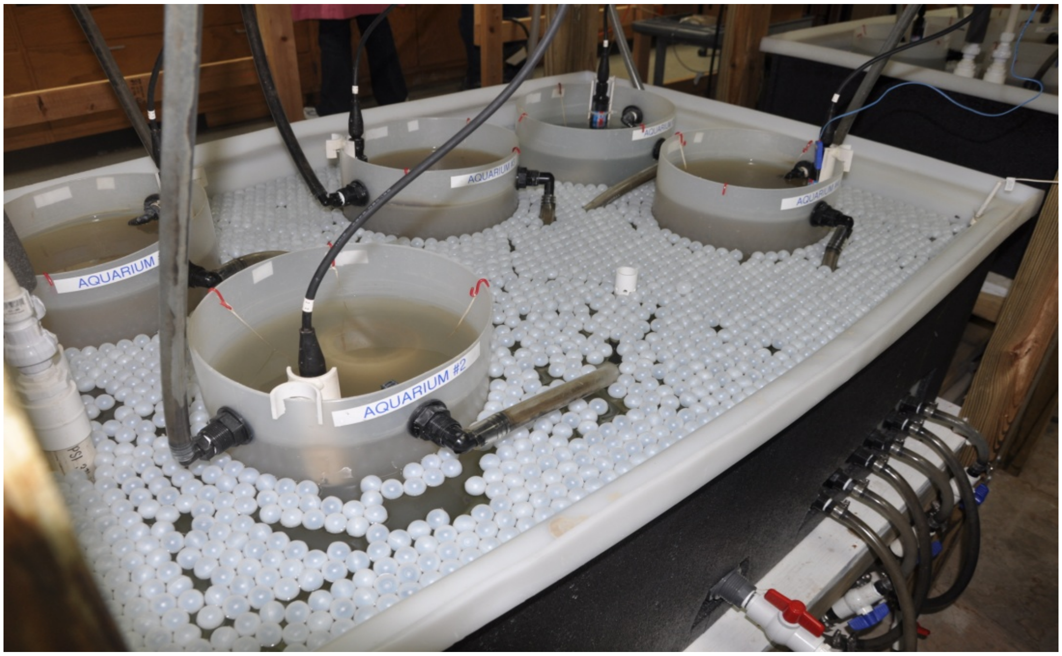

Figure 5. One of the three FLEES modules, containing five aquaria that are serving as individual experimental units. Note the insulation covering the outside of the module and the plastic beads floating on the water surface used for controlling temperature.

This control system allows the FLEES to maintain TSS levels in each aquarium with a minimum of fluctuation. The computer program also allows the timing intervals between NTU measurements to be varied.

Based on experiments conducted to date, TSS levels have been successfully maintained at levels as high as 600 mg/L. The FLEES should be able to maintain levels as high as 800 mg/L, but this would likely require a larger slurry holding tank. Levels greater than this are problematic as the sediment tends to drop quickly out of suspension, requiring an almost constant inflow of slurry. This could also create a layer of sediment settling on the bottom of the aquarium, which may create conditions counter to experimental objectives of testing only TSS exposure.

Performance. A series of operational runs is performed before beginning an experiment to ensure that the FLEES is operating properly. An example of FLEES performance in maintaining TSS in experimental aquaria is shown in Figure 6. In this example, module 1 (WB 1) was used to test whether suspended sediment could be maintained over a three-day period, a duration of exposure appropriate for most experiments simulating typical exposures in the field. Aquarium #1 (AQ1-1) was pulsed with sediment on day two and then allowed to settle without any additional sediment added. Aquarium #2 (AQ1-2) was set to consistently maintain a turbidity of 125 NTU over the three-day period. Aquaria #3 and #5 (AQ1-3 and AQ1-5) were programmed to maintain a turbidity of 300 NTU over the three-day period. The sediment pulses are clearly evident in the lines shown in Figure 6; however, programming flexibility allows the TSS concentration in each aquarium to vary only about 20-40 NTU around the target concentration. The figure shows that the FLEES can maintain the desired turbidities (or calibrated concentrations) over a period of time required to meet project objectives.

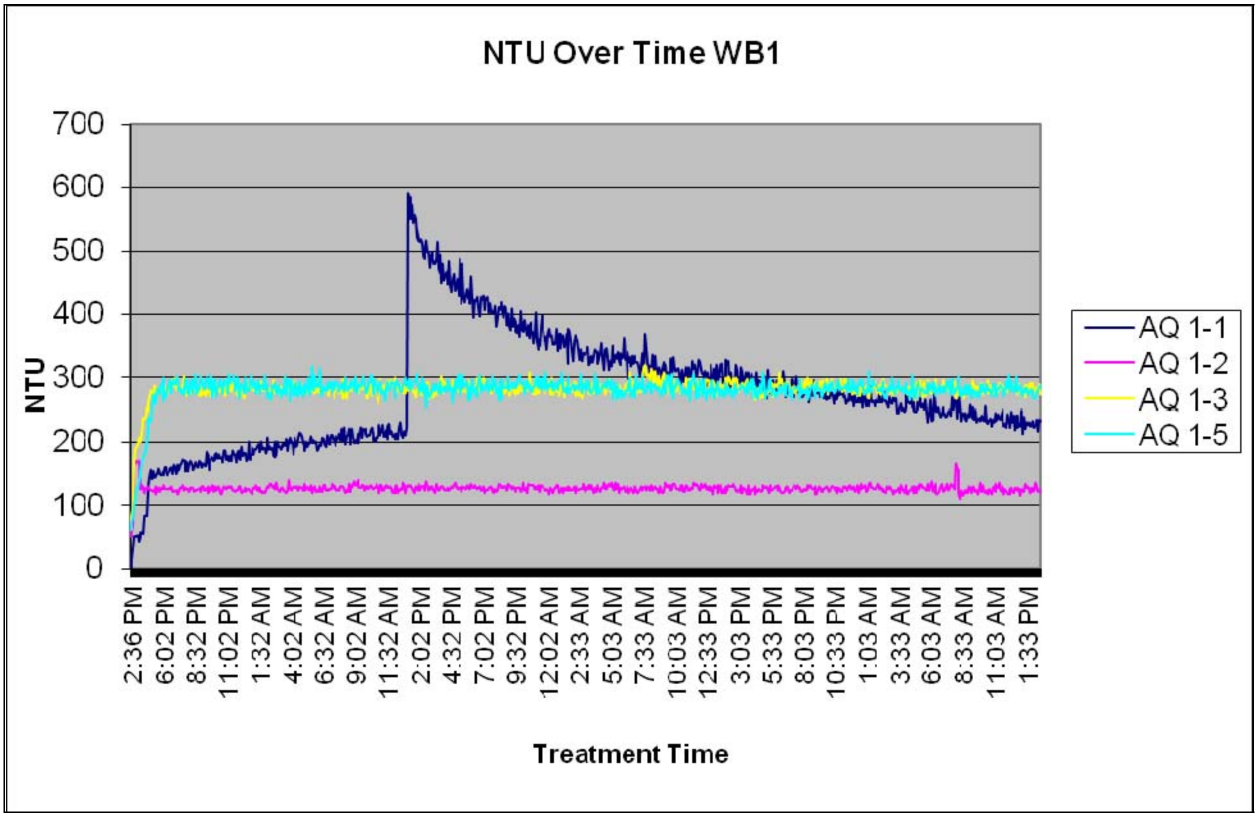

Figure 6. Example NTU data from four aquaria from a single module (or water bath, WB) in the FLEES over a three-day period.

Portability. The FLEES is designed for transport to a remote site for testing organisms that might not survive shipping to a laboratory location or that require saline water. All of the plumbing, electrical, and data connections are made with unions or plugs so they may be disassembled for transport and easily reassembled at the remote location.

SUMMARY: This technical note describes an automated laboratory organism exposure system designed for simulation studies of suspended sediment effects on specific species driving EWs for dredging and disposal projects. The FLEES can benefit dredging project managers by providing effects data to support informed, science-based decisions about setting and revising EWs. An ability to provide scientifically defensible data to support decision making can improve the execution of dredging and dredged material disposal for controversial projects (e.g., those involving contaminated sediments and conflicting disposal options); reduce disagreements with resource agencies, local port authorities, and other stakeholders; and increase the Corps' credibility with other agencies that embrace risk management techniques. The FLEES has the capability to also expose organisms to levels of turbidity/TSS concentrations consistent with those generated by vessel traffic, freshets, and storms; thus enabling dredging operations to be placed into perspective with other sources of sediment resuspension (e.g., Reine et al. 2007).

POINTS OF CONTACT: for additional information, contact Dr. Burton Suedel (601-634-4578, *Burton.Suedel@usace.army.mil*) or Mr. Charles Lutz (601-634-2489, *Charles.H.Lutz@usace.army.mil*). This technical note should be cited as follows:

Lutz, C. H., D. G. Clarke, B. C. Suedel. 2012. *A fish larvae and egg exposure system (FLEES) for evaluating the effects of suspended sediments on aquatic life.* DOER Technical Notes Collection. ERDC TN-DOER-E32. Vicksburg, MS: U.S. Army Engineer Research and Development Center. http://el.erdc.usace.army.mil/.

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